Load Frequency Control in Two Area Power System

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

Bachelor of Technology in Electrical Engineering

By

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CERTIFICATE

This is to certify that the project entitled, "**Load Frequency control in Two Area Power System**" submitted by **Siddhahast Mohapatra** is an authentic work carried out by him under my supervision and guidance for the partial fulfillment of the requirements for the award of **Mid semester report Submission** in **Electrical Engineering** at **National Institute of Technology, Rourkela (Deemed University).**

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ABSTRACT

This research project presents decentralized control scheme for Load Frequency Control in a multi-area Power System by appreciating the performance of the methods in a single area power system. A number of modern control techniques are adopted to implement a reliable stabilizing controller. A serious attempt has been undertaken aiming at investigating the load frequency control problem in a power system consisting of two power generation unit and multiple variable load units. The robustness and reliability of the various control schemes is examined through simulations.

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CHAPTER 1:

INTRODUCTION

For large scale power systems which consists of inter-connected control areas, load frequency then it is important to keep the frequency and inter area tie power near to the scheduled values. The input mechanical power is used to control the frequency of the generators and the change in the frequency and tie-line power are sensed, which is a measure of the change in rotor angle. A well designed power system should be able to provide the acceptable levels of power quality by keeping the frequency and voltage magnitude within tolerable limits.

Changes in the power system load affects mainly the system frequency, while the reactive power is less sensitive to changes in frequency and is mainly dependent on fluctuations of voltage magnitude. So the control of the real and reactive power in the power system is dealt separately. The load frequency control mainly deals with the control of the system frequency and real power whereas the automatic Voltage regulator loop regulates the changes in the reactive power and voltage magnitude. Load frequency control is the basis of many advanced concepts of the large scale control of the power system.

CHAPTER 2 :

BACKGROUND AND LITERARTURE RIVIEW

Need for Maintenance of Constant frequency

Mathematical Modeling of Power System

Pole Placement Technique

Optimal Control Technique

State Space Modeling of two Area Power System

(A)Reasons for the Limits on Frequency:

Following are the reasons for keeping a strict limit on the system frequency variation:

1. The speed of the alternating current motors depends on the frequency of the power supply. There are situations where speed consistency is expected to be of high order.
2. The electric clocks are driven by the synchronous motors. The accuracy of the clocks are not only dependent on the frequency but also is an integral of the this frequency error.
3. If the normal frequency id 50 Hertz and the system frequency falls below 47.5 Hertz or goes up above 52.5 Hertz then the blades of the turbine are likely to get damaged so as to prevent the stalling of the generator.
4. The under frequency operation of the power transformer is not desirable. For constant system voltage if the frequency is below the desired level then the normal flux in the core increases. This sustained under frequency operation of the power transformer results in low efficiency and over-heating of the transformer windings.
5. The most serious effect of subnormal frequency operation is observed in the case of Thermal Power Plants. Due to the subnormal frequency operation the blast of the ID and FD fans in the power stations get reduced and thereby reduce the generation power in the thermal plants. This phenomenon has got a cumulative effect and in turn is able to make complete shutdown of the power plant if proper steps of load shedding technique is not engaged. It is pertinent to mention that, in load shedding technique a sizable chunk of load from the power system is disconnected from the generating units so as to restore the frequency to the desired level.

(B)LOAD FREQUENCY CONTROLAND MATHEMATICAL MODELLING OF VARIOUS COMPONENTS:

If the system is connected to a number of different loads in a power system then the system frequency and speed change with the governor characteristics as the load changes. If it is not required to keep the frequency constant in a system then the operator is not required to change the setting of the generator. But if constant frequency is required the operator can adjust the speed of the turbine by changing the governor characteristic as and when required. If a change in load is taken care by two generating stations running at parallel then the complexity of the system increases. The possibility of sharing the load by two machines is as follow:

- Suppose there are two generating stations that are connected to each other by tie line. If the change in load is either at A or at B and the generation of A is alone asked to regulate so as to have constant frequency then this kind of regulation is called **Flat Frequency Regulation.**
- The other possibility of sharing the load the load is that both A and B would regulate their generations to maintain the constant frequency. This is called **parallel frequency regulation.**
- The third possibility is that the change in the frequency of a particular area is taken care of by the generator of that area thereby the tie-line loading remains the same. This method is known as **flat tie-line loading control**.
- In **Selective Frequency control** each system in a group is takes care of the load changes on its own system and does not aid the other systems un the group for changes outside its own limits.

- In **Tie-line Load-bias control** all the power systems in the interconnection aid in regulating frequency regardless of where the frequency change originates. The equipment consists of a master load frequency controller and a tie line recorder measuring the power input on the tie as for the selective frequency control.

The error signal i.e. Δf and ΔP_{tie} are amplified, mixed and transformed to real power command signal ΔP_V which is sent to the prime mover to call for an increase in the torque. The prime mover shall bring about a change in the generator output by an amount ΔP_G which will change the values of Δf and ΔP_{tie} within the specified tolerance. The first step to the analysis of the control system is the mathematical modeling of the system's various components and control system techniques.

©MATHEMATICAL MODELLING OF GENERATOR

Applying the swing equation of a synchronous machine to small perturbation, we have:

$$\frac{2H}{\omega}\frac{d^2\Delta\delta}{dt^2} = \Delta Pm - \Delta Pe$$

Or in terms of small deviation in speed

$$\frac{d\Delta\frac{\omega}{\omega_s}}{dt} = \frac{1}{2H}(\Delta Pm - \Delta Pe)$$

Taking Laplace Transform , we obtain

$$\Delta\Omega(s) = \frac{1}{2Hs}[\Delta Pm(s) - \Delta Pe(s)]\text{----------eqn(1)}$$

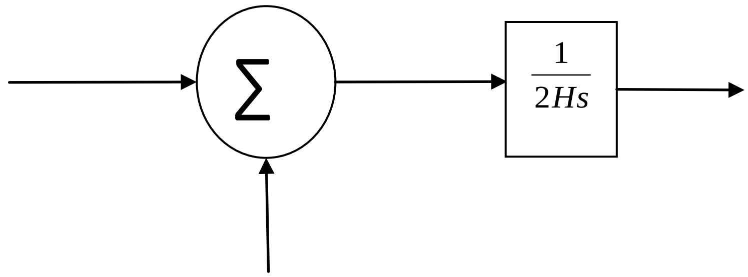

Figure-1 Mathematical modeling block diagram for generator

(D)MATHEMATICAL MODELLING OF LOAD

The load on the power system consists of a veriety of electrical drives. The equipments used for lighting purposes are basically resistive in nature and the rotating devices are basically a composite of the resistive and inductive components. The speed-load characteristic of the composite load is given by:

$$\Delta P_e = \Delta P_L + D\Delta\omega \text{ ---------------eqn(2)}$$

where ΔP_L is the non-frequency- sensitive load change,

$D\Delta\omega$ is the frequency sensitive load change.

D is expressed as percent change in load by percent change in frequency.

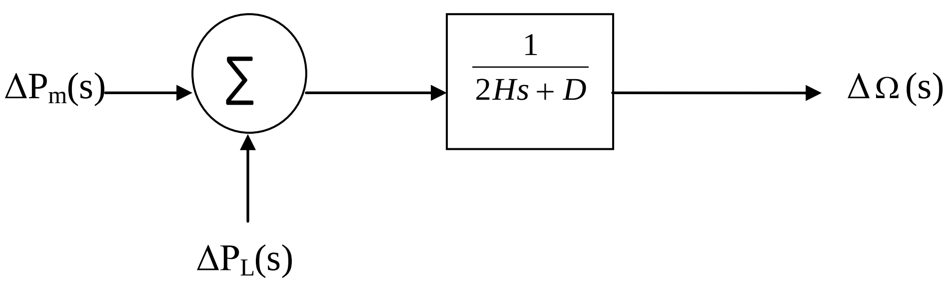

Figure-2 :Mathematical modeling Block Diagram for Load

(E)MATHEMATICAL MODELLING FOR PRIME MOVER:

The source of power generation is commonly known as the prime mover. It may be hydraulic turbines at waterfalls, steam turbines whose energy comes from burning of the coal, gas and other fuels. The model for the turbine relates the changes in mechanical power output ΔP_m to the changes in the steam valve position ΔP_V.

$$G_T = \frac{\Delta P_m(s)}{\Delta P_V(s)} = \frac{1}{1+\tau_T s} \text{ -----------------eqn(3)}$$

Where τ_T ,the turbine constant is, in the range of 0.2 to 2.0 seconds.

(F)MATHEMATICAL MODELLING FOR GOVERNOR

When the electrical load is suddenly increased then the electrical power exceeds the mechanical power input. As a result of this the deficiency of power in the load side is extracted from the rotating energy of the turbine. Due to this reason the kinetic energy of the turbine i.e. the energy stored in the machine is reduced and the governor sends a signal to supply more volumes of water or steam or gas to increase the speed of the prime-mover so as to compensate speed deficiency.

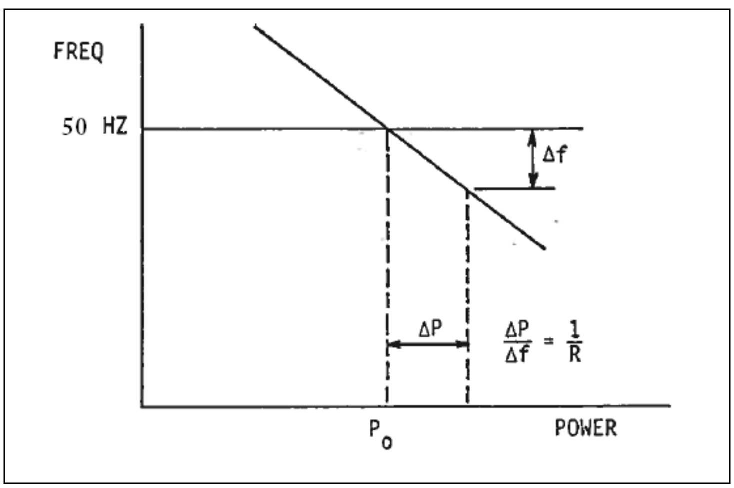

Figure-3 :Graphical Representation of speed regulation by governor

The slope of the curve represents speed regulation R. Governors typically have a speed regulation of 5-6 % from no load to full load.

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta f \text{ ---------------eqn(4)}$$

Or in s- domain

$$\Delta P_g(s) = \Delta P_{ref} - \frac{1}{R}\Delta\Omega(s) \text{-----------------------eqn(5)}$$

The command ΔP_g is transformed through hydraulic amplifier to the steam valve position command ΔP_V. We assume a linear relationship and consider simple time constant τ_g we have the following s-domain relation:

$$\Delta P_V(s) = \frac{1}{1+\tau_g}\Delta P_g(s) \text{------------------eqn(6)}$$

Combining all the block diagrams from earlier block diagrams for a single are system we get the following:

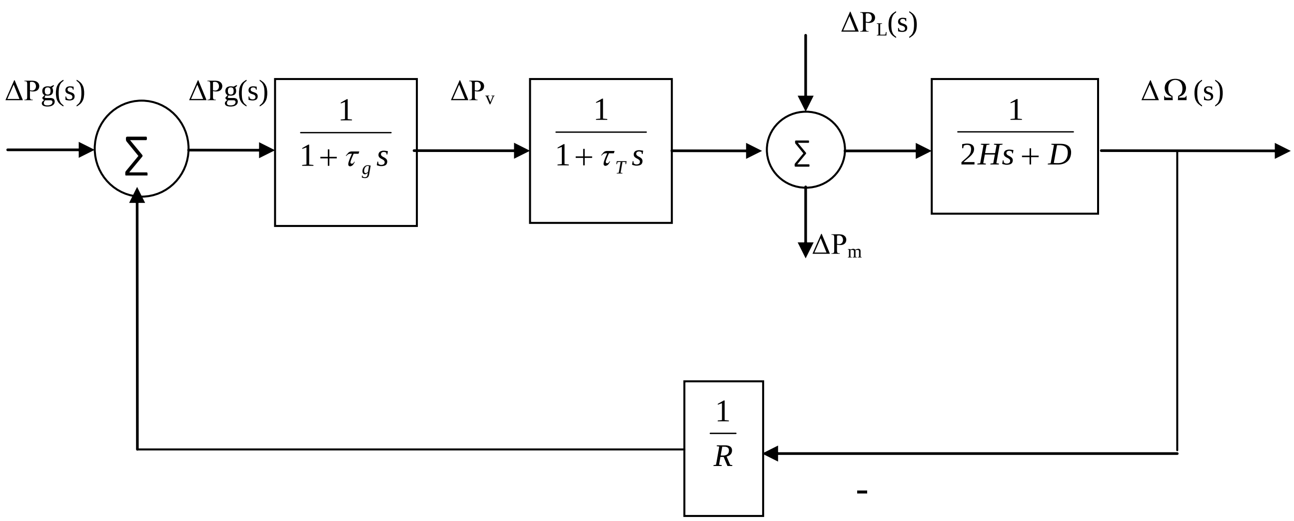

Figure-4: Mathematical Modelling of Block Diagram of single system consisting of Generator, Load, Prime Mover and Governor.

(G)AUTOMATIC GENERATION CONTROL:

If the load on the system is increased suddenly then the turbine speed drops before the governor can asjust the input of the steam to the new load. As the change in the value of speed diminishes the error signal becomes smaller and the position of the governor and not of the fly balls get closer to the point required to maintain the constant speed. One way to restore the speed or frequency to its nominal value is to add an integrator on the way. The integrator will unit shall monitor the the average error over a period of time and will overcome the offset. Thus as the load of the system changes continuously the generation is adjusted automatically to restore the frequency to the nominal value. This scheme is known as automatic generation control. In an interconnected system consisting of several pools, the role of the AGC is to divide the load among the system, stations and generators so as to achieve maximum economy and reasonably uniform frequency.

(H)AGC IN A SINGLE AREA:

With the primary LFC loop a change in the system load will result in a steady state frequency deviation , depending on the governor speed regulation. In order to reduce the frequency deviation to zero we must provide a reset action by introducing an integral controller to act on the load reference setting to change the speed set point. The integral controller increases the system type by 1 which force the final frequency deviation to zero. The integral controller gain must be adjusted for a satisfactory transient response.

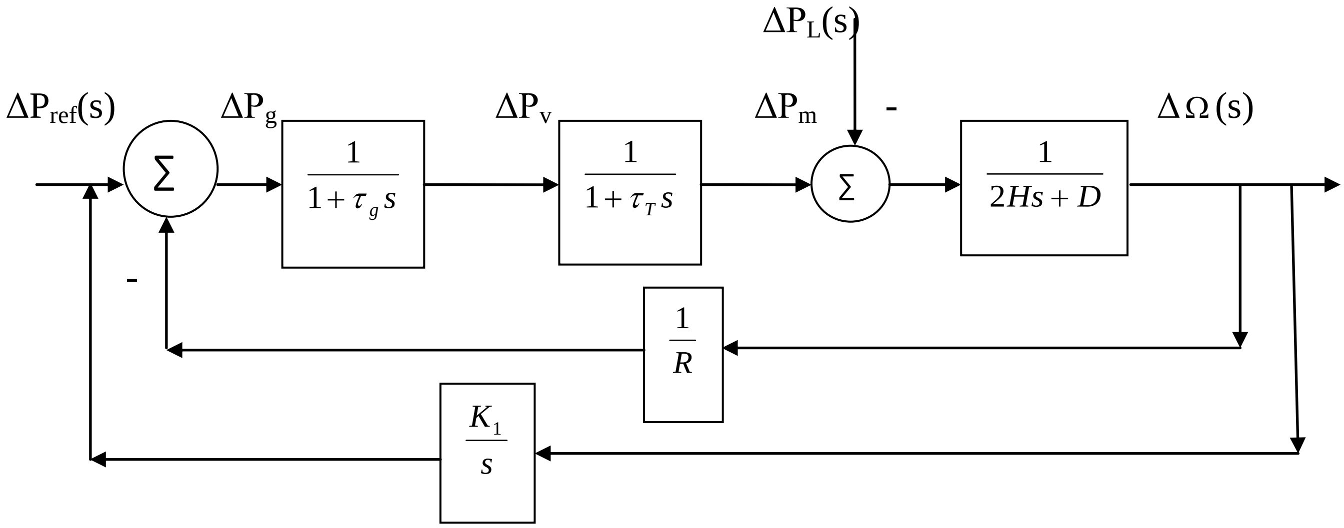

Figure 5: Mathematical modeling of AGC for an isolated power system.

The closed loop transfer function of the control system is given by:

$$\frac{\Delta\Omega(s)}{-\Delta P_L(s)} = \frac{s(1+\tau_g s)(1+\tau_T s)}{s(2Hs+D)(1+\tau_g s)(1+\tau_T s)+K_1+{}^{s}\!/_{R}} \text{------------------eqn(6)}$$

(I)AGC IN THE MULTIAREA SYSTEM:

In many cases a group of generators are closely coupled internally and swing in unison. Furthermore, the generator turbines tend to have the same response characteristics. Such a group of generators are said to be coherent. The it is possible to let the LFC loop represent the whole system and the group is called the control group. For a two area system, during normal operation the real power transferred over the tie line is given by

$$P_{12} = \frac{|E_1||E_2|}{X_{12}} \sin\delta_{12}$$

Where $X_{12} = X_1 + X_{tie} + X_2$ and $\delta_{12} = \delta_1 - \delta_2$

For a small deviation in the tie-line flow $\Delta P_{12} = \left.\frac{dP_{12}}{d\delta_{12}}\right|_{\delta_{12}} \Delta\delta_{12}$

$$=P_s \Delta\delta_{12}$$

The tie-line power deviation then takes on the form

$$\Delta P_{12} = P_s(\Delta\delta_1 - \Delta\delta_2)$$

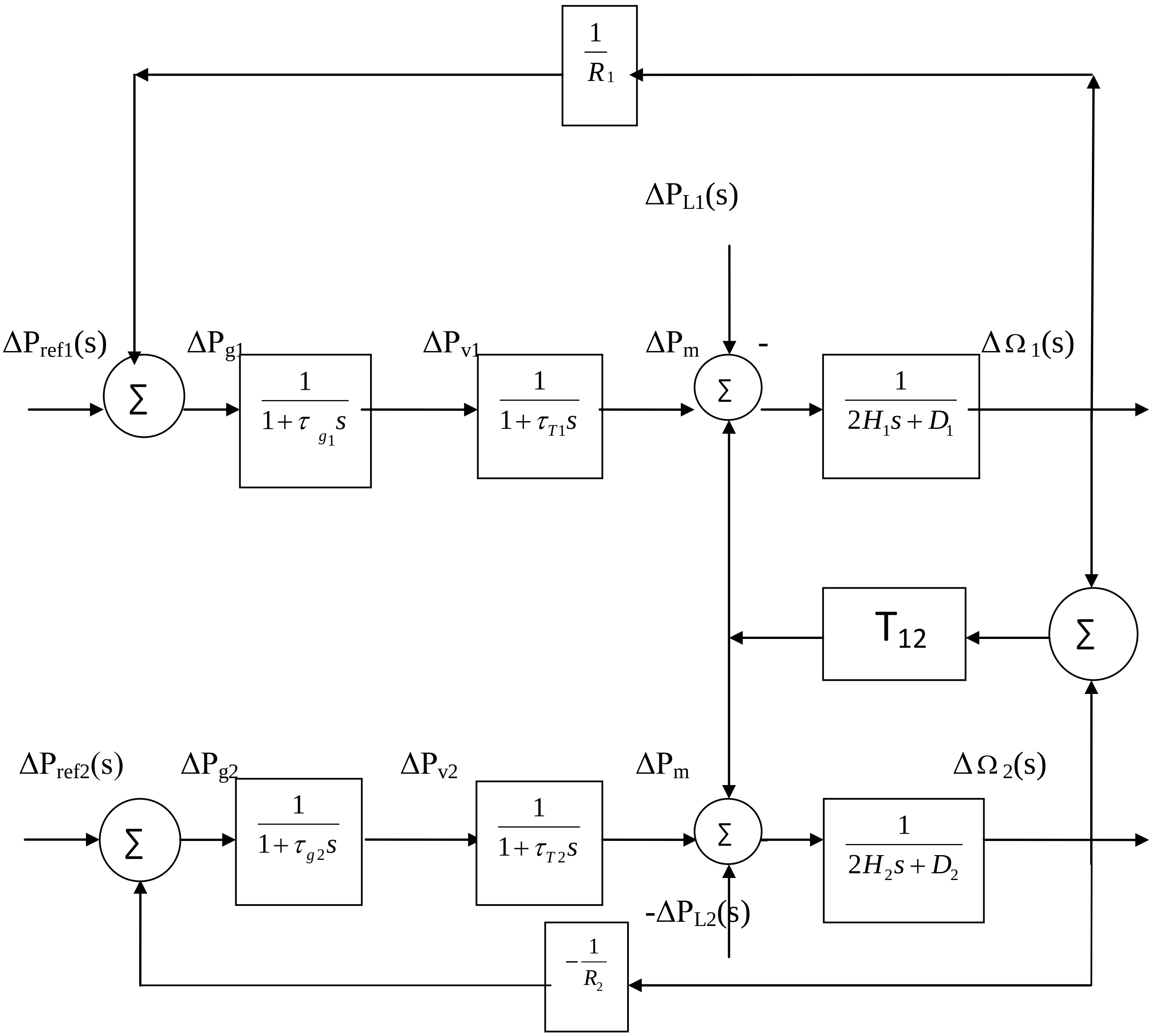

Figure-6:Two area system with primary loop LFC

Modern Control design is especially based on the multivariable state vector system. In this design algorithm we make use of the state variable parameters that can be obtained from the system. For the systems where all the state variables are not available a state estimator is designed.

Various Methodologies to implement the Feedback control:

(J)Pole Placement Technique:

The control is achieved by feedback the state variables through a regulator with constant gains. Consider the system in the state variable form:

X(t)=Ax(t) + Bu(t)------------------------------equation (7)

Y(t)=Cx(t)--equation (8)

The pole placement design allows all the roots of the system characteristic equation to be placed in desired location, which eventually results in a regulator with constant gain vector K.

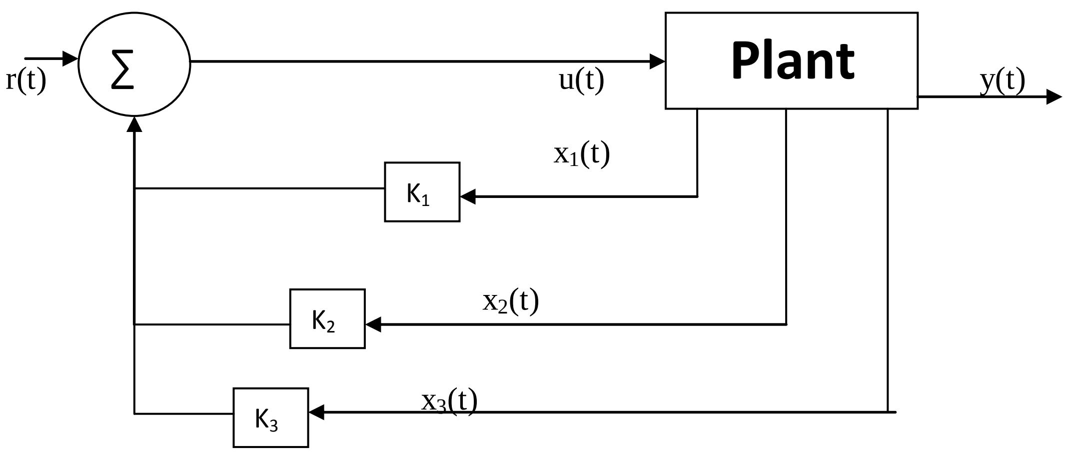

Figure 7:Control Design via Pole Placement

Now if we consider the Figure 11 above, the block diagram with the following state feedback control

$$U(t)= -Kx(t)\text{-------------equation (9)}$$

where K is a 1×n vector of constant feedback gains. The control system input r(t) is assumed to be zero. The purpose of the method is to reduce all the values of the state variables to be zero when the states have been perturbed. Substituting equation 9 in equation 7 the compensated system state variable representation becomes

$$X(t)= (A- BK)\ X(t)= A_f X(t)\text{------equation (10)}$$

The compensated system characteristic equation is

$$|sI- A + BK| =0 \text{ ----------equation (11)}$$

The function $[K,A_f]$= placepol(A,B,C,p) is developed for the pole placement design. The matrices A,B,C are the system matrices and p is row matrix containing the desired closed-loop poles. The function returns the gain matrix K and the closed-loop matrix A_f. For a multi input system K= place(A,B,p), which uses a more reliable algorithm.

(L)Optimal Control System:

It is a technique applied in the control system design that is executed by minimizing the performance index of the system variables. In this section we discuss the design of the optimal controllers for the linear systems with quadratic performance index, which is also referred to as the linear quadratic regulator. The objective of the optimal regulator design is to determine a control law $\mathbf{u^*(x,t)}$ which can transfer the system from its initial state to the final state by minimizing the performance index. The performance index that is widely used is the quadratic performance index and is based on the minimum energy criterion.

Consider the plant as discussed :

X(t)=Ax(t) + Bu(t)

The problem is to find the vector **K** of the control law

U(t)= -K(t)*x(t)

Which minimizes the value of the quadratic performance index **J** of the form:

J= $\int_{t0}^{tf}(x'Qx+u'Ru)dt$ ---------(15)

Where Q is a positive semidefinite matrix and **R** is real symmetric matrix. **Q** is a positive definite matrix if all its principal minors are non-negative. The choice of the elements of **Q** and **R** allows the relative weighting of thr individual state variables and individual control inputs.

To obtain the solution we make use of the method of Langrange multipliers using an n vector of the unconstrained equation

[x,λ,u,t]= [x'Qx + u'Ru] + λ'[Ax + Bu – x']-----------------------(16)

The optimal values determined are found by equating the partial derivative to zero.

$$\frac{\partial L}{\partial \lambda}=AX^*+Bu^*-x'^*=0\Rightarrow x'^*=AX^*+Bu^* \quad (17)$$

$$\frac{\partial L}{\partial u}=2Ru^*+\lambda^*B=0\Rightarrow u^*=-\frac{1}{2}R^{-1}\lambda'B \quad (18)$$

$$\frac{\partial L}{\partial x}=2x'^*+\lambda'+\lambda'A=0\Rightarrow \lambda'=-2Qx^*-A'\lambda \quad (19)$$

Assuming that there exists a symmetric , time varying positive definite matrix **p(t)** satisfying

$$\lambda = 2p(t)x^* \tag{20}$$

Substituting (20) in (18) we get

$$U^*(t) = -R^{-1}B'p(t)x^* \tag{21}$$

Obtaining the derivative of (20) we get

$$\lambda = 2(px^* + px^*) \tag{22}$$

Finally we equate (19) and (22)

$$p(t) = -p(t)A - A'p(t) - Q + p(t)BR^{-1}B'p(t) \tag{23}$$

The above equation is known as the Riccati equation.

Compensators are generally used to satisfy all the desired specifications in a system. But in most of the cases the system needs to fulfill some more specifications that are difficult to attain in case of a compensated system. As an alternative to this we mainly use Optimal Control system. The trial and error system for the compensated design system makes it cumbersome for the designers to attain the specifications. This trial and error procedure works well for the system with a single input and a single output. But for a multi-input-multi-output system the trial and error method is done away and replaced with Optimal Control design method where the trial and error uncertainties are eliminated in parameter optimization method. It consists of a single performance index specially the integral square performance index. The minimization of the performance index is done using the Lyapunov stability theorem in order to yield better system performance for a fixed system configuration. The values of Q and R has to carefully selected and if the responses are unsuitable then the some other values of Q and R has to be selected. K is automatically generated and the closed loop responses are found.

(M)Problem Statement:

Consider an uncertain power system arising out of an N-interconnected system with every sample of an uncertain system having the pair of equations as given below:

$$X(t)= [A_{ii} + \Delta A_{ii}(t)] X_i(t) + \sum [A_{ij} + \Delta A_{ij}(t)]X_j(t) + \sum [B_{ij} + \Delta B_{ij}(t)]U_j(t) + \sum [\Gamma_{ij} + \Delta \Gamma_{ij}(t)]D_j(t) \qquad (24)$$

$$Y(t)= C_{ii}X_i(t) + \sum C_{ij}X_j(t) \qquad (25)$$

It is assumed that the matrices A,B,C,Γ are of appropriate dimensions and are completely controllable and observable.

Equations 24 and 25 can also be written in a more compact form as

$$X(t)= [\mathbf{A} + \mathbf{\Delta} \mathbf{A}(t)] X(t) + [\mathbf{B} + \mathbf{\Delta} \mathbf{B}(t)]U(t) + [\mathbf{\Gamma} + \mathbf{\Delta} \mathbf{\Gamma}(t)]D(t) \qquad (26)$$

$$Y(t)= CX(t) \qquad (27)$$

Imperfect knowledge of the matrices A and B are represented determistically by the matrices **Δ A**(t) , **Δ B**(t) and **Δ Γ**(t) that can change continuously with the time within the range of the parameter variations. The main objective of interest is to determine the control function U(t)= -KX(t) whwre K is a constant gain matrix. Here in this case the U(t) accomplished the objective. So determing the control matrix is same as determining the constant gain matrix K.

In the LQR design the stability robustness is not is more exposed to the uncertainties of parametric variations. LQR design based on the nominal systems does not guarantee the stability of the perturbed systems.

Consider the linear uncertain system,

$$X(t)= [\mathbf{A} + \boldsymbol{\Delta}\, \mathbf{A}(t)]\, X(t) + [\mathbf{B} + \boldsymbol{\Delta}\, \mathbf{B}(t)]U(t) \qquad (27)$$

Where A(n×n) and B(n×m) are the nominal parameter matrices and **Δ A**(t) and **B**(t) are the associated continuous matrices that define the ranges of the uncertainty in the parameters.

Assuming that A and B are completely controllable and observable the condition stated in (27) are said to be matched if there exists a continuous time matrix functions G(r(t)) and H(s(t)) such that:

$$\boldsymbol{\Delta}\, \mathbf{A}(t)= \mathbf{A}G(r(t)) \qquad (28)$$

$$\boldsymbol{\Delta}\, \mathbf{B}(t)= \mathbf{A}H(s(t)) \qquad (29)$$

The matrices G and H are continuous time-variant matrices and continuous functions of r(t) and s(t) respectively. They are the uncertain parameters that are assumed to be bounded by the conditions:

$$H^T(s(t))*H(s(t))<= I \qquad (30)$$

$$G^T(r(t))*G(r(t))<= I \qquad (31)$$

As discussed before the main aim is to define a control input of the form U(t)= -KX(t) where K belongs to $R^{m\times n}$ so that the law stabilizes the matched uncertain system in (27).

Consider the system in (27) that satisfies the matching conditions in (28) and (29). Let Q(n×m) be any positive-definite symmetric matrix and there exists an optimal $\psi^*>0$ such that all the values of ψ that are greater than or equal to ψ^* have a positive definite solution of the following equation :

$$\mathbf{A}^T P + P\mathbf{A} - 2\psi^* P\mathbf{B}R^{-1}\mathbf{B}^T P + \eta G^T(r(t))G(r(t)) + Q = [0] \qquad (32)$$

It is assumed that the system is liner and the uncertainties are discared.

Hence $\mathbf{\Delta\, A}(t)=0$

$\mathbf{\Delta\, B}(t)=0$

Therefore the equation 32 is reduced to

$\mathbf{A}^T P + P\mathbf{A} - 2\psi^* P\mathbf{B}R^{-1}\mathbf{B}^T P + Q = [0]$ which is nothing but the ricarti equation.

(N)Two Area Modelling of a Power System:

Take into consideration an i^{th} area power system and we write the differential equation governing the operation under normal condition where we assume that the disturbances in the system are zero.

Differential Equation of the governor:

$$\Delta x'_{vi} = -\frac{1}{T_{gi}}\Delta x_{vi}(t) - \frac{1}{T_{gi}R_i}\Delta f_i(t) + \frac{1}{T_{gi}}\Delta p_{ci}(t) \qquad (33)$$

For Turbine Generator:

$$\Delta p'_{gi} = -\frac{1}{T_{ti}}\Delta p_{gi}(t) + \frac{1}{T_{ti}}\Delta x_{vi}(t) \qquad (34)$$

For Power System:

$$\Delta f'_i(t) = -\frac{D_i f_0}{2H_i}\Delta f_i(t) - \frac{f_0}{2H_i}(\Delta p_{tie,i} - \Delta p_{gi}) \qquad (35)$$

Tie Line Power Equation:

$$\Delta p'_{tie,i}(t) = \sum T_{ij}(\Delta f_i - \Delta f_j) \quad (36)$$

Developing the state space model we need the matrices A and B.

$$A=\begin{bmatrix} 0 & T_{12} & 0 & 0 & 0 & -T_{12} & 0 \\ -\frac{f_0}{2H_1} & -\frac{f_0 D_1}{2H_1} & \frac{f_0}{2H_1} & 0 & 0 & 0 & 0 \\ 0 & 0 & -\frac{1}{T_{t1}} & \frac{1}{T_{t1}} & 0 & 0 & 0 \\ 0 & -\frac{1}{T_{g1}R_1} & 0 & -\frac{1}{T_{g1}} & -\frac{1}{T_{g1}} & 0 & 0 \\ -\frac{f_0}{2H_2} & 0 & 0 & 0 & 0 & -\frac{f_0 D_2}{2H_2} & \frac{f_0}{2H_2} \\ 0 & 0 & 0 & 0 & 0 & -\frac{1}{T_{g2}R_2} & -\frac{1}{T_{t2}} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}; B=\begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ \frac{1}{T_{g1}} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & \frac{1}{T_{g2}} \end{bmatrix}$$

$$X=\begin{bmatrix} \Delta p_{tie}(t) \\ \Delta f_1(t) \\ \Delta p_{g1}(t) \\ \Delta x_{v1}(t) \\ \Delta f_2(t) \\ \Delta p_{g2}(t) \\ \Delta x_{v2}(t) \end{bmatrix}; U=\begin{bmatrix} \Delta p_{c1}(t) \\ \Delta p_{c2}(t) \end{bmatrix}$$

$\Delta x_{vi}(t)$ - Incremental change in the valve position;

$\Delta p_{gi}(t)$ - Incremental change in the power generation;

$\Delta p_{ci}(t)$ - Incremental change in the speed changer postion;

And rest of the symbols used have their usual meanings as in the case of the isolated system. The subscript *I* denotes the area under consideration.

CHAPTER 3:

SIMULATIONS, RESULTS AND DISCUSSIONS

Pole Placement Technique and Optimal Control Technique for Isolated System

Matlab Code for the Simulating the system

Discussions

Pole Placement Technique for an Isolated Area System:

A. Compensated System Response

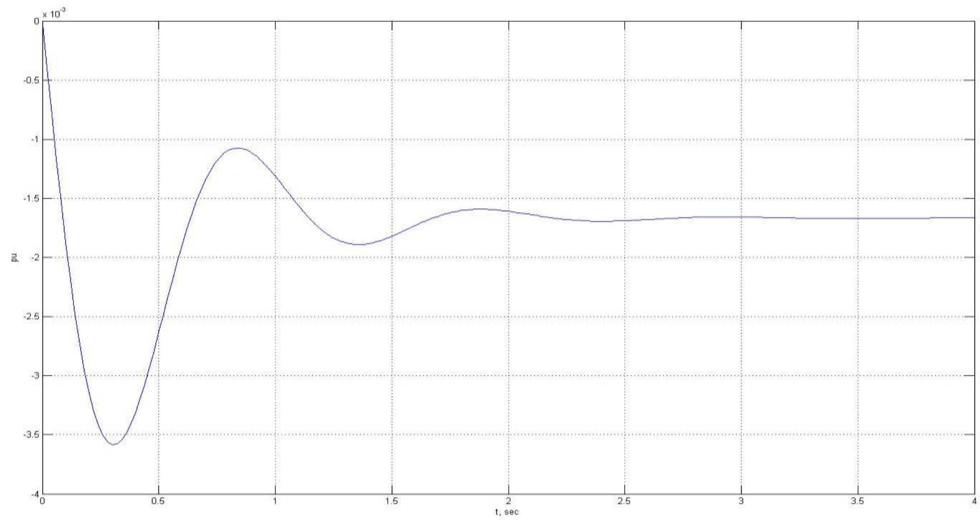

Figure:8 Step response for compensated System.

B. Uncompensated system Response

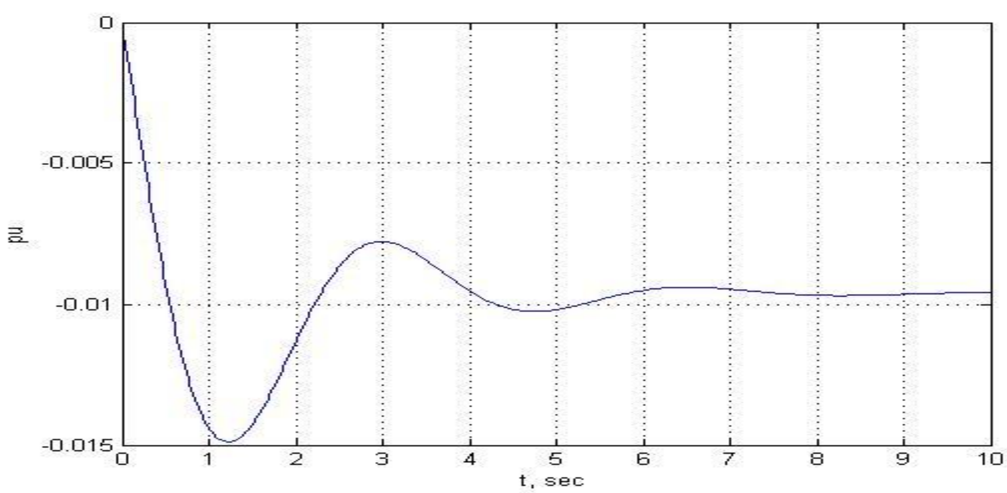

Figure 9:Step response for Uncompensated System

MATLAB CODE FOR THE POLE PLACEMENT TECHNIQUE IN SINGLE AREA ISOLATED SYSTEM

```
PL = 0.2;

A = [-5  0  -100; 2  -2  0; 0  0.1  -0.08];

B = [0;  0;  -0.1]; BPL = B*PL;

C = [0  0  1];  D = 0;

disp('(a)')

t=0:0.02:10;

[y, x] = step(A, BPL, C, D, 1, t);

figure(1), plot(t, y), grid

xlabel('t, sec'), ylabel('pu')

r =eig(A)

disp('(b) Open sim12xxb.mdl in SIMULINK WINDOW and click on simulation')

disp(' ')

disp('(c) Pole-placement design')

P=[-2.0+j*6   -2.0-j*6   -3];

[K, Af] = placepol(A, B, C, P);

t=0:0.02:4;

[y, x] = step(Af, BPL, C, D, 1, t);

figure(2), plot(t, y), grid

xlabel('t, sec'), ylabel('pu')

disp('(d) Open sim12xxd.mdl in SIMULINK WINDOW and click on simulation')
```

Placepol Function

```
n=length(A);
  for i=1:n;
  S(:,n+1-i) = A^(n-i)*B;
  end
  if rank(S)~=n
  error('System is not state controllable')
  else
T=inv(S);
   end
q=zeros(1,n); q(n)=1;
H=q*T;
p=poly(P);
AL=zeros(n);
for i=1:n+1
AL=AL+p(n+2-i)*A^(i-1);
end
K=H*AL;
Af=A-B*K;
 fprintf('Feedback gain vector K  \n'),
for i=1:n, fprintf('  %g',K(i)),fprintf(' '),end,fprintf('\n\n')
D=0;
if length(C(:,1)) > 1 return
```

```
else
[num, den]=ss2tf(A,B,C,D,1);
for i=1:length(num)
if abs(num(i)) <=1e-08 num(i)=0;else end,end
[numclsd, denclsd]=ss2tf(Af,B,C,D,1);
for i=1:length(numclsd)
if abs(numclsd(i)) <=1e-08 numclsd(i)=0;else end,end
fprintf('Uncompensated Plant')
GH = tf(num, den)

fprintf('Compensated system closed-loop')
T = tf(numclsd, denclsd)
fprintf('Compensated system matrix A - B*K \n')
disp(Af)
end
```

RESULTS :For Pole Placement Design of the single isolated Area System.

Feedback gain vector

K=[4.2   0.8   0.8]

Compensated system closed-loop

Transfer function:

$$\frac{-0.1s^2 - 0.7s - 1}{s^3 + 7s^2 + 52s + 120}$$

Uncompensated Plant

Transfer function:

$$\frac{-0.1s^2 - 0.7s - 1}{s^3 + 7.08s^2 + 10.56s + 20.8}$$

*Compensated system matrix A-B*K=* $\begin{bmatrix} -5.0 & 0 & -100.0 \\ 2.0 & -2.0 & 0.0 \\ 0.42 & 0.18 & 0.0 \end{bmatrix}$

Settling time for the uncompensated system is 4seconds and that for a compensated system is 2.5seconds.

Optimal control Design for single area isolated System:

```
PL=0.2;

A = [-5  0  -100; 2  -2  0; 0  0.1  -0.08];

B = [0;  0;  -0.1]; BPL=PL*B;

C = [0  0  1];

D = 0;

Q = [20 0  0; 0  10 0; 0  0  5];

R = .15;

[K, P] = lqr2(A, B, Q, R)

Af = A - B*K

t=0:0.02:1;

[y, x] = step(Af, BPL, C, D, 1, t);

plot(t, y), grid

xlabel('t, sec'), ylabel('pu')

disp('(b) Open sim12xx1.mdl in SIMULINK WINDOW and click on simulation')
```

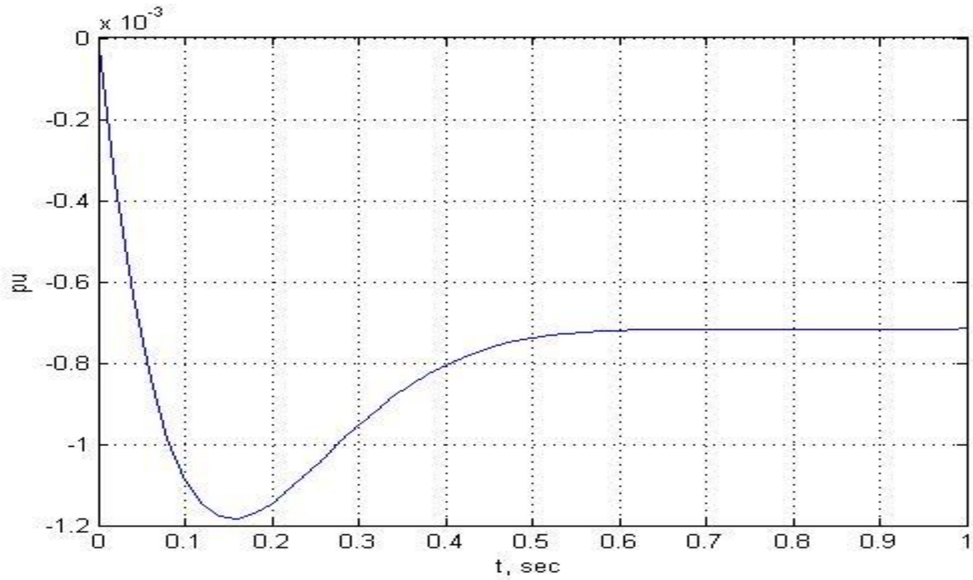

Figure 10: Frequency Deviation Step response for optimal control design of a single area isolated system

For Q=[20 0 0;0 10 0;0 0 5]

K = [6.4128 1.1004 -112.6003]

$$P = \begin{bmatrix} 1.5388 & 0.3891 & -9.6192 \\ 0.3891 & 2.3721 & -1.6506 \\ -9.6192 & -1.6506 & 168.9 \end{bmatrix}$$

$$Af = \begin{bmatrix} -5 & 0 & -100 \\ 2 & -2 & 0 \\ 0.6143 & 0.21 & -11.34 \end{bmatrix}$$

Settling time is 0.6 seconds.

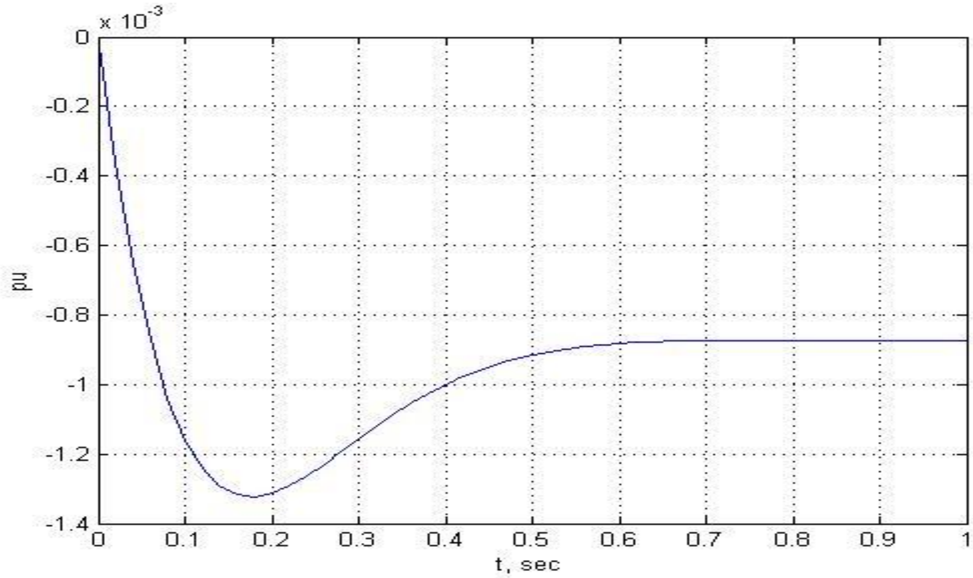

Figure 11: Frequency Deviation Step response for optimal control design of a single area isolated system

For Q=[15 0 0;0 5 0;0 0 1]

K= [5.1995   0.2944 -101.2115]

$$P = \begin{bmatrix} 1.1768 & 0.2057 & -7.7993 \\ 0.2057 & 1.2247 & -0.4415 \\ -7.7993 & -0.4415 & 151.87 \end{bmatrix}$$

$$Af = \begin{bmatrix} -5 & 0 & -100 \\ 2 & -2 & 0 \\ 0.52 & 0.1294 & -10.202 \end{bmatrix}$$

Settling time is 0.6seconds.

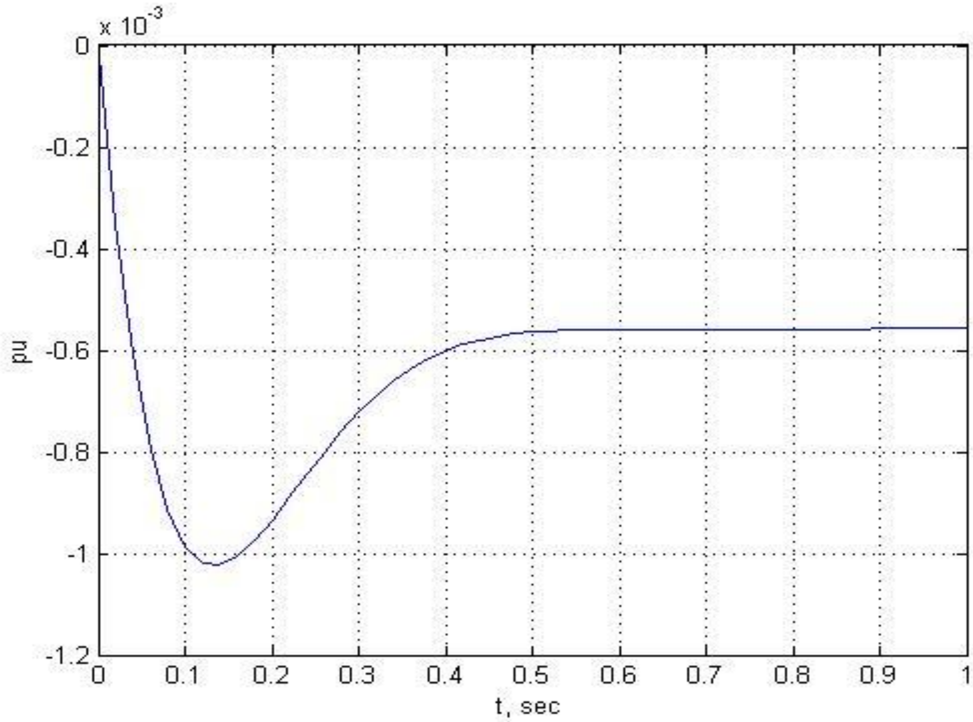

Figure 12: Frequency Deviation Step response for optimal control design of a single area isolated system

For Q=[30 0 0;0 20 0;0 0 5]

K =[8.4546   2.3265 -129.3656]

$$P = \begin{bmatrix} 2.2150 & 0.7181 & -12.6818 \\ 0.7181 & 4.6226 & -3.4897 \\ -12.6818 & -3.4897 & 194.05 \end{bmatrix}$$

$$Af = \begin{bmatrix} -5 & 0 & -100 \\ 2 & -2 & 0 \\ 0.8455 & 0.3326 & -13.0166 \end{bmatrix}$$

Settling time is 0.5 seconds.

DISCUSSION:

From the above simulations it is clear that the set of figures (Figure 8 & 9) which depicts the deviation in frequency of the isolated system has more ripples and its counterpart in Figure 10,11 and 12 has less ripples. It is clearly obvious from the graphical representation of the step response that the settling time is more uncompensated system than that for a compensated system while using pole placement technique. When we look into the step response in the Optimal Controller design then its clear that the settling time is less. The system reaches equilibrium faster than that for the controllers using pole placement design. In general there are two situations where compensation is required. The first case is when the system is unstable. The second case is when the system is stable but the settling time is to reach faster. Hence using pole placement technique is nothing but using the compensation scheme to reduce the settling time of the system. It is clearly shown that the system reached faster to a steady state in compensated system than for an uncompensated system.

Optimal Control Design of two area power System

A. Simulation results when 2^{nd} area input is changed.

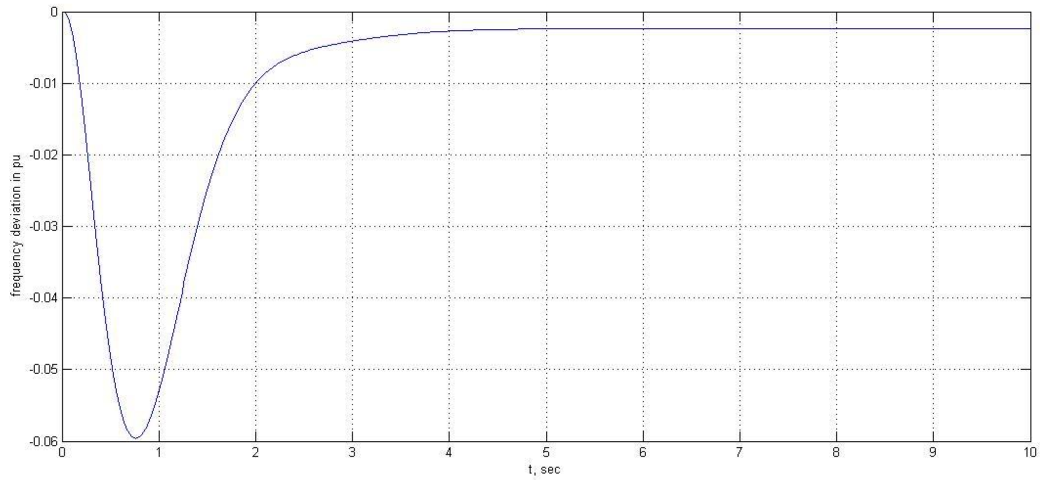

Figure 13: Frequency deviation Δf1 .

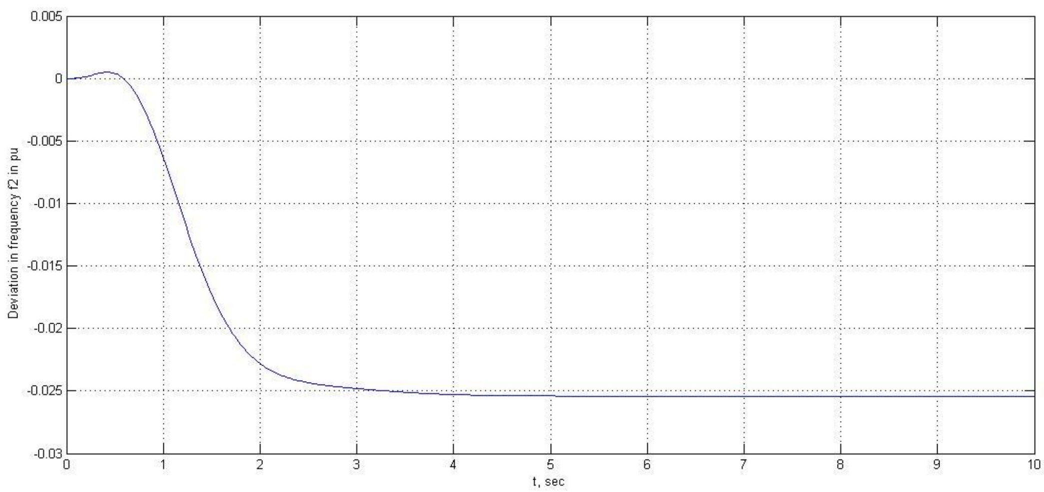

Figure 14: Frequency deviation Δf2

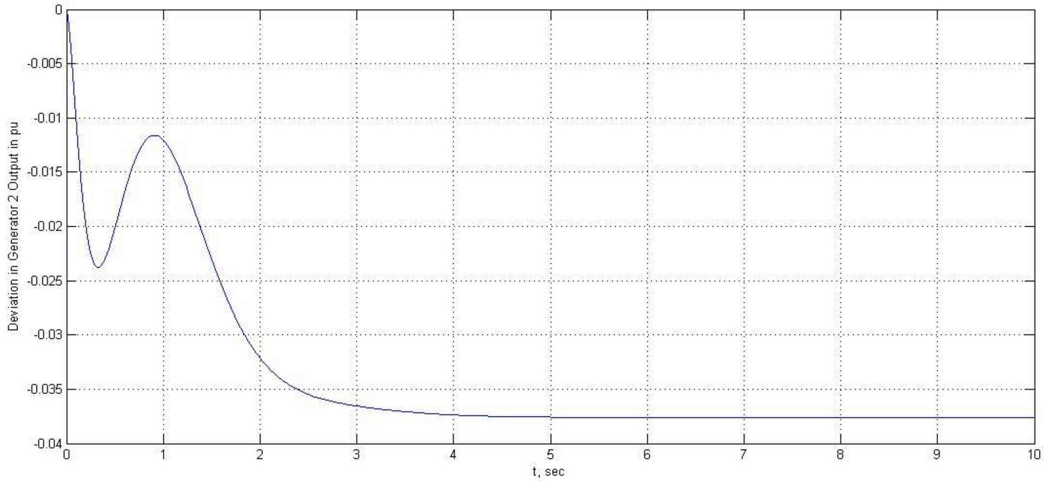

Figure 15: Deviation in Generator 2 Output P_{g2}.

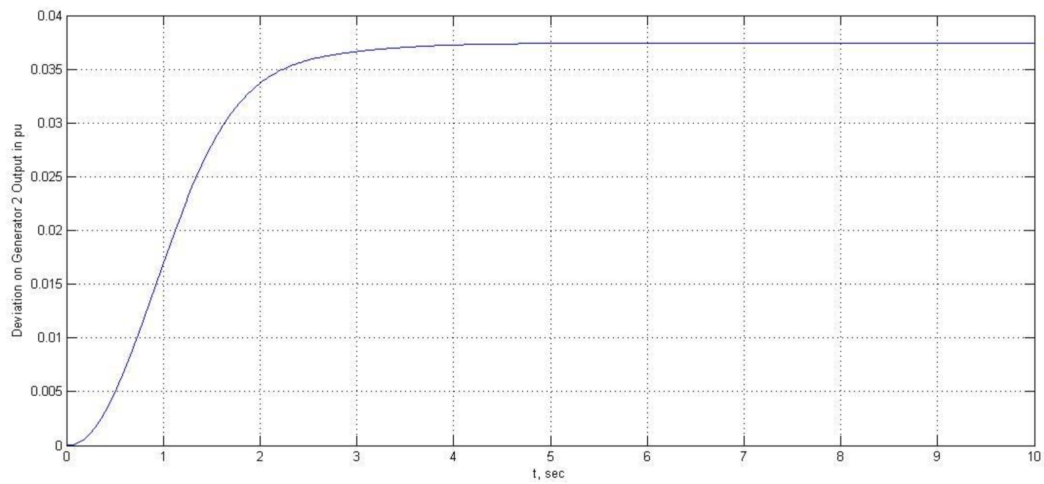

Figure 16: Deviation in Generator 1 Output P_{g1}.

B. Simulation Results when Input to Area 1 is varied.

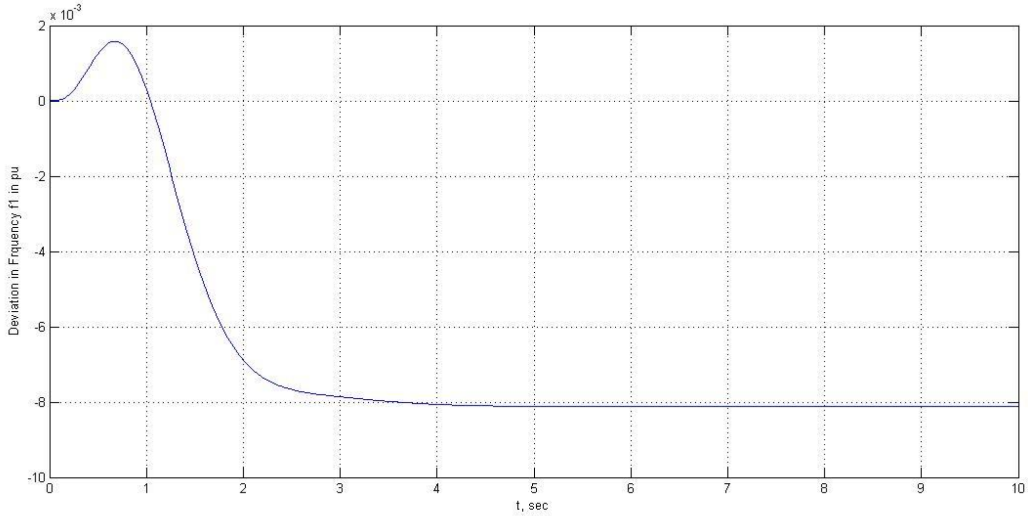

Figure 17: Frequency Deviation Δf1

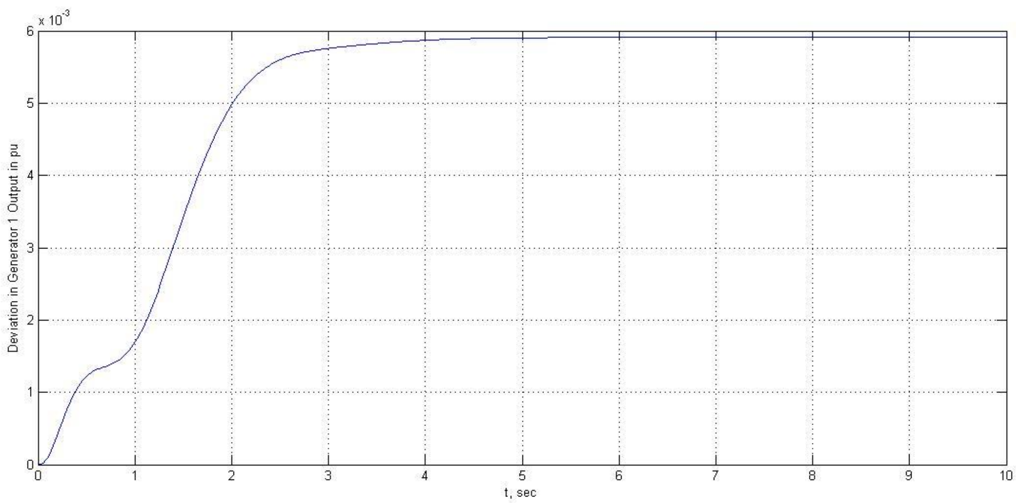

Figure 18: Deviation in Generator 2 Output P_{g2}.

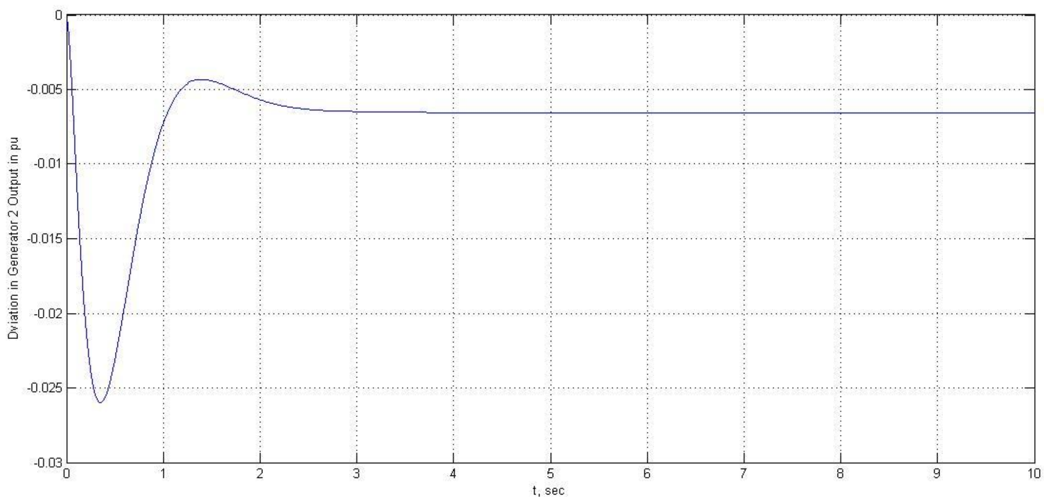

Figure 19: Deviation in Generator 1 Output P_{g1}.

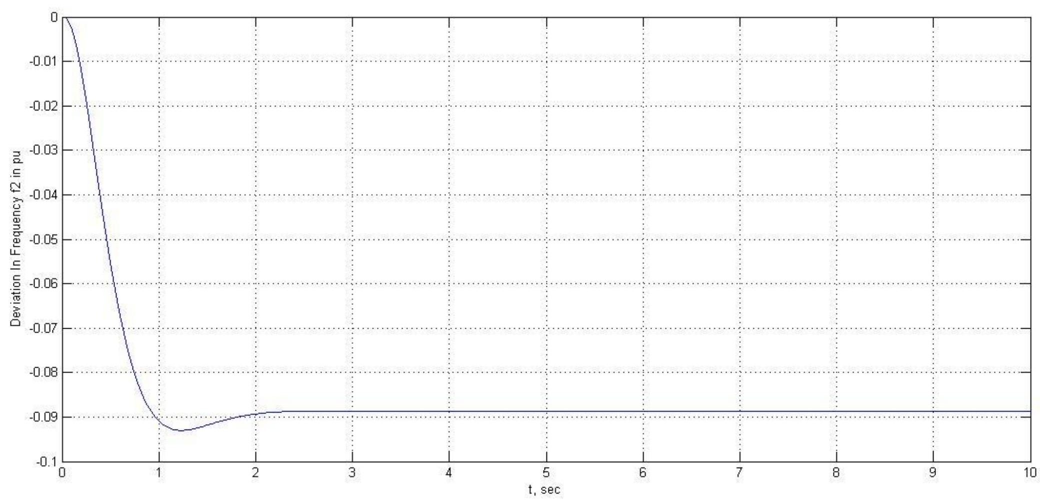

Figure 20: Frequency deviation $\Delta f2$

MATLAB CODE FOR OPTIMAL CONTROL DESIGN IN A TWO AREA NETWORK

```
PL= [0.1;0.0];

A = [0.05 6 0 -6 0 0 0; 0 -3.33 3.33 0 0 0 0 ;-5.2083 0 -12.5 0 -0.545 0 0; 0.545 0 0 0 -0.05 0 0;0
0 0 6 -0.05 6 0;0 0 0 0 0 -3.33 3.33;0 0 0 0 -5.2083 0 -12.5];

B = [0 0;0 0;0 12.5;0 0;0 0;0 0;12.5 0]; BPL=B*PL;

C = [0 0 0 0 0 0 1];

D = 0;

Q = [1 0 0 0 0 0 0;0 1 0 0 0 0 0;0 0 1 0 0 0 0;0 0 0 1 0 0 0;0 0 0 0 1 0 0;0 0 0 0 0 1 0;0 0 0 0 0 0
1];

R = [1 0;0 1];

[K, P] = lqr2(A, B, Q, R)

Af = A - B*K

t=0:0.02:10;

[y, x] = step(Af, BPL, C, D, 1, t);

plot(t, y), grid

xlabel('t, sec'), ylabel('pu')

disp('(b) Open sim12xx1.mdl in SIMULINK WINDOW and click on simulation')
```

RESULTS:

K =	0.2587	0.1618	0.0211	1.9479	0.6165	1.2311	0.6296
	0.8336	1.4724	0.6685	-0.4770	0.0108	0.0997	0.021

P =	0.6014	0.5082	0.0667	0.3635	0.0517	0.1087	0.0207
	0.5082	0.7364	0.1178	-0.1081	0.0202	0.0642	0.0129
	0.0667	0.1178	0.0535	-0.0382	0.0009	0.0080	0.0017
	0.3635	-0.1081	-0.0382	5.8492	0.6154	0.8986	0.1558
	0.0517	0.0202	0.0009	0.6154	0.4366	0.3839	0.0493
	0.1087	0.0642	0.0080	0.8986	0.3839	0.6127	0.0985
	0.0207	0.0129	0.0017	0.1558	0.0493	0.0985	0.0504
Af =	0.0500	6.0000	0.0000	-6.0000	0.0000	0.0000	0.0000
	0.0000	-3.3300	3.3300	0.0000	0.0000	0.0000	0.0000
	-15.6278	-18.4044	-20.8567	5.9624	-0.6803	-1.2462	-0.2640
	0.5450	0.0000	0.0000	0.0000	-0.0500	0.0000	0.0000
	0.0000	0.0000	0.0000	6.0000	-0.0500	6.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	-3.3300	3.3300
	-3.2343	-2.0228	-0.2640	-24.3485	-12.9141	-15.3893	-20.3697

DISCUSSION :

Figures 16 ,17 ,18 ,19 denote the variation the frequencies and power generation of the two area power system when there is a variation in the input parameters of area 1. Similarly the Figures 20, 21, 22, 23 denote the variation of the above quantities when a variation in the input to the area 2 occurs, which clearly suggests that a decentralized control of the load frequency is achievable through Optimal Control Technique. Whenever the speed regulation to the area 2 generation is negative the load demand increases with respect to that of area 1, hence the frequency of area 2 deceases and the generation of power by the generator 2 also decreases. In order to meet the load demand the generator 1 has to increase generation and since the load has increased slightly with respect to the generation capacity it follows a slight deviation in the system frequency is ought to occur that is evidently shown in the simulations.

Similarly when we look into the system in another way by changing the parameters in the input of generator 1 then the load demand increases with respect to the generation. As a result of which the frequency in the 1st area decreases and the generation capacity also decreases. In order to balance the generation and supply the generator in the second area must generate more power but since the load is slightly more than that of the generation capacity the system frequency decreases slightly, which is verified from the above simulation results.

The following parameters are used from Ref.[6] and the scalar C is chosen in such a manner that each iteration shows the variation in the certain parameter of the system.

$$A=\begin{bmatrix} 0.05 & 6 & 0 & -6 & 0 & 0 & 0 \\ 0 & -3.33 & 3.33 & 0 & 0 & 0 & 0 \\ -5.2083 & 0 & -12.5 & 0 & -0.545 & 0 & 0 \\ 0.545 & 0 & 0 & 0 & -0.05 & 0 & 0 \\ 0 & 0 & 0 & 6 & -0.05 & 6 & 0 \\ 0 & 0 & 0 & 0 & 0 & -3.33 & -3.33 \\ 0 & 0 & 0 & 0 & -5.2083 & 0 & -12.5 \end{bmatrix};\ B=\begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 12.5 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 12.5 \end{bmatrix};$$

$R=I_{2\times 2}$; $Q= I_{7\times 7}$.

CHAPTER 4:

CONCLUSION

The project presents a case study of designing a controller that can bear desirable results in a two area power system when the input parameters to the system is changed. Two methods of Load Frequency Control was studied taking an isolated power system into consideration. It was seen that the Optimal controller design bore better results and achieved desired reliability under changes in the input parameter. Hence an attempt was made to extend the Optimal Control design to a two area network. The assumptions taken under consideration strictly followed that the system operation was normal throughout and the simulations were obtained without the presence of the integral controllers. Lyapunov stability study revealed that by minimizing the system performance index the optimal controller can be designed that improves the system stability and performance drastically over the pole placement method with extensively depended on trial and error process. In fact there is a huge scope of improvement in this area where the power system study can be extended to a multi-area system that shall ensure stability in closed loop system.

CHAPTER 5:

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